
Evaluation of Next Generation Military Vehicle Cooling Systems

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Outline

Unclassified

- Thermal Challenges in a Military Environment
- Traditional vs. Alternative Approach
- Thermal Testing
- Thermal Tool
- Pilot Project – Applying the Simulation
- Results
- Next Steps

Thermal Challenges

Unclassified

Military needs differ from most commercial applications

- Longer service life
- Shorter operational life
- Environmental extremes
- Worldwide operation
- Adverse operating conditions
- Both on- and off-road mission profiles
- Minimal maintenance during combat operation



Thermal Challenges

Unclassified

Cooling System Design Factors

- Severe shock & vibration
- Long term storage
- Challenging longitudinal & lateral slopes
- Corrosive battlefield atmosphere & fording
- Ground-hop capability
- Airside clogging of heat exchangers
- Ambient temperature extremes & high altitudes



Thermal Challenges

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Military vehicles are facing ever increasing challenges of meeting cooling system requirements

- Additional armor
- Power upgrades
- Extremely hot environments
- Heat loads associated with hybrids
- Adverse operating conditions

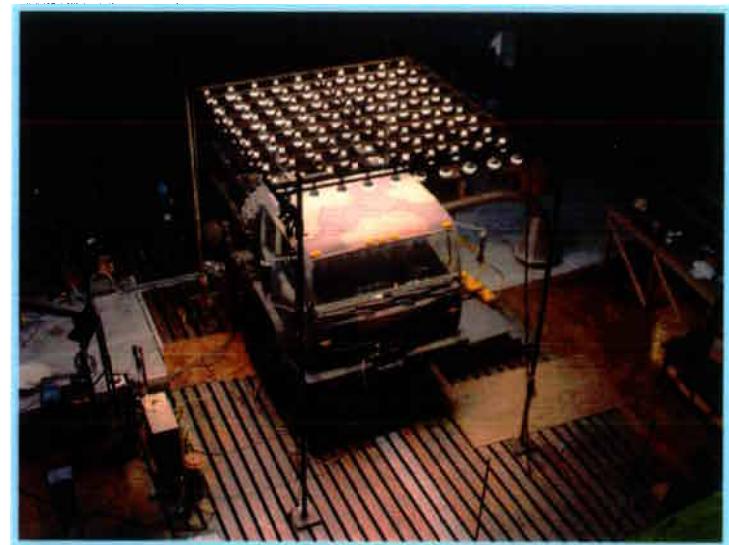


Traditional Approach

Unclassified

Meet thermal challenges through thermal testing

- Optimize cooling system performance
- Select improved components – Radiator & Fan
- Conduct vehicle thermal testing
- Evaluate impact to cooling system



Alternative Approach

Unclassified

Share thermal challenge through an interactive technique

- Connect vehicle level simulation with vehicle test
- Link 1D simulations to testing process
 - Evaluate multiple vehicle variants/configurations
 - Accomplish rapid optimization of thermal system
 - Identify best candidates to test
 - Achieve thermal goals

Alternative Approach

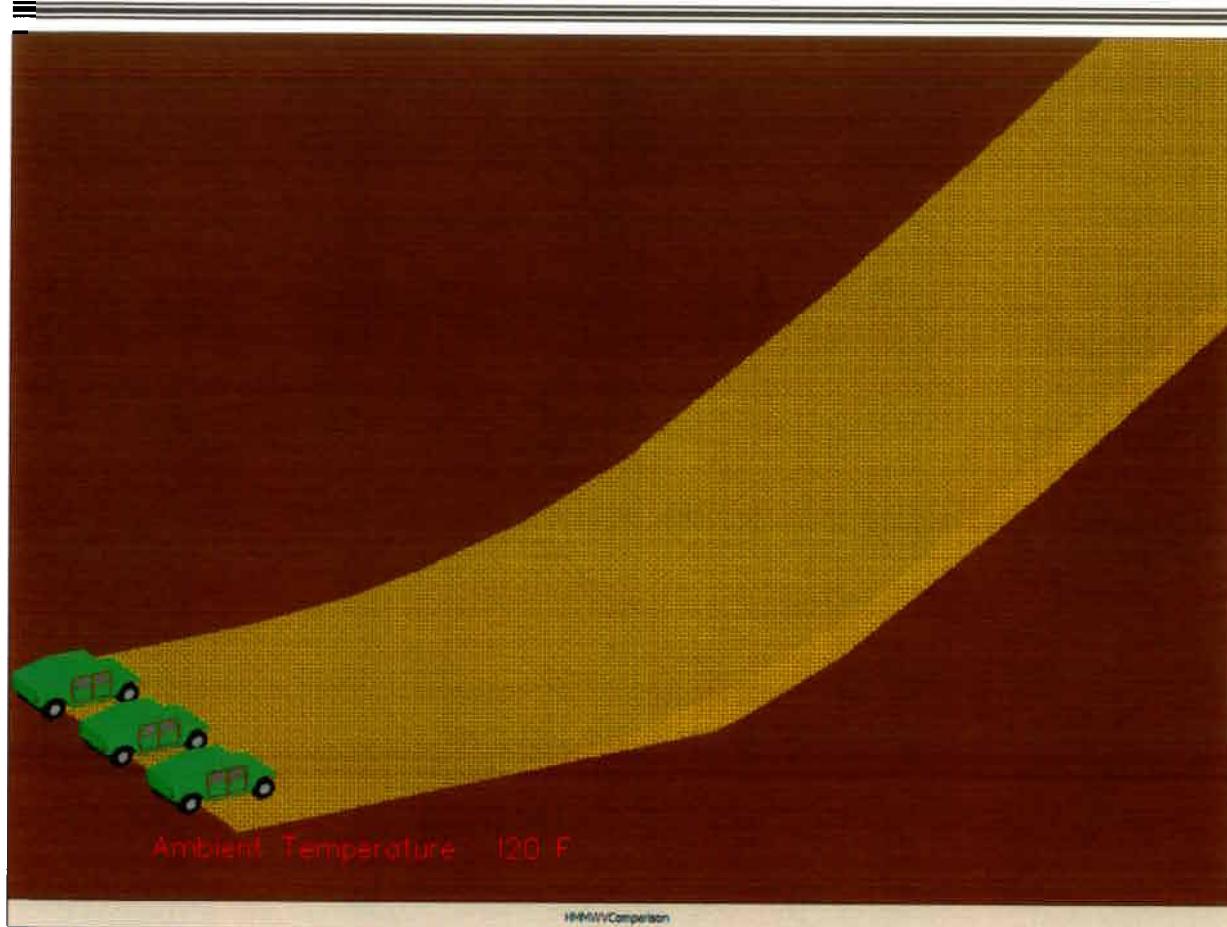
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Benefits:

- Minimize number of tests
- Maximize test results
- Save time
- Reduce cost
- Enhance cooling system performance capabilities

Thermal Testing

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Objectives

Maintain critical temperatures within specified limits while operating at:

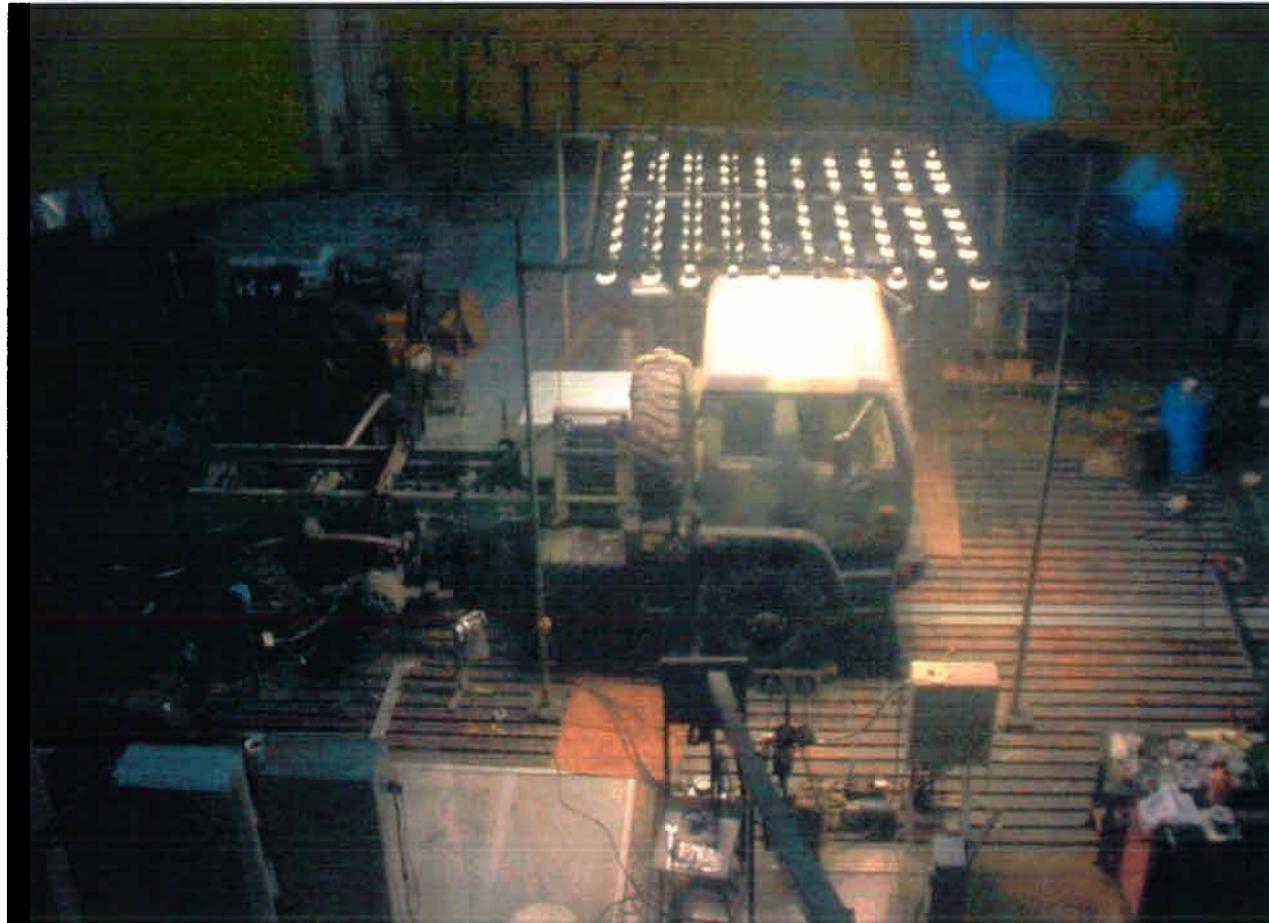
- Full power
- Full load
- Ambient 120°F

Specified Limits

- Engine Coolant 230°F
- Engine Oil 275°F
- Transmission Oil 300°F

Thermal Testing

Unclassified



Test Conditions

- Full Power
- Full Load
- Ambient 120°F
- 5 mph wind velocity
- Solar radiation

Data Captured

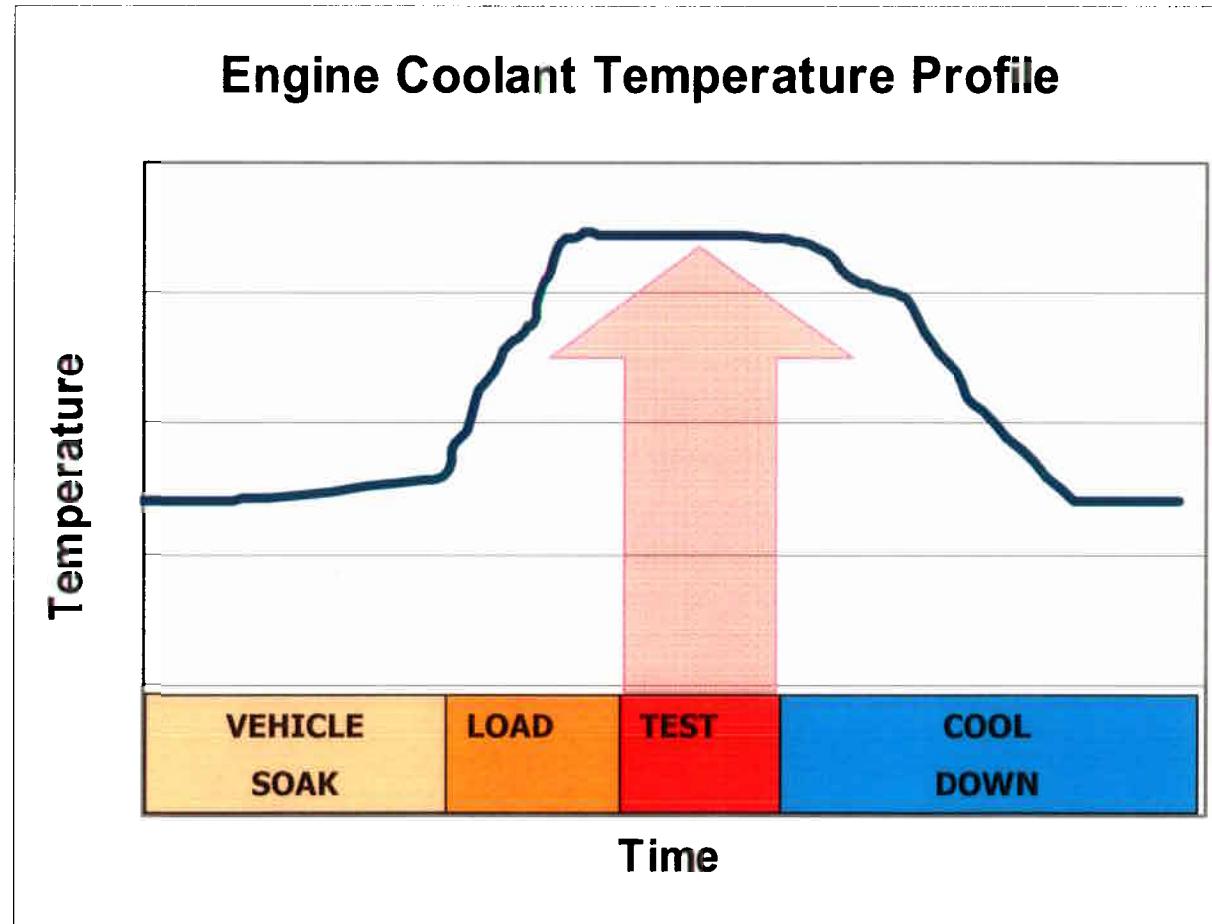
- Engine Coolant
- Engine Oil
- Transmission Oil

Results

Determine if vehicle cooling system meets requirements in various configurations

Thermal Testing

Unclassified



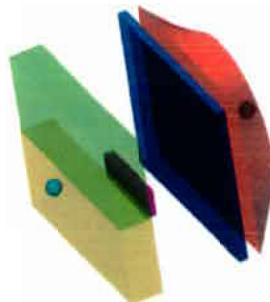
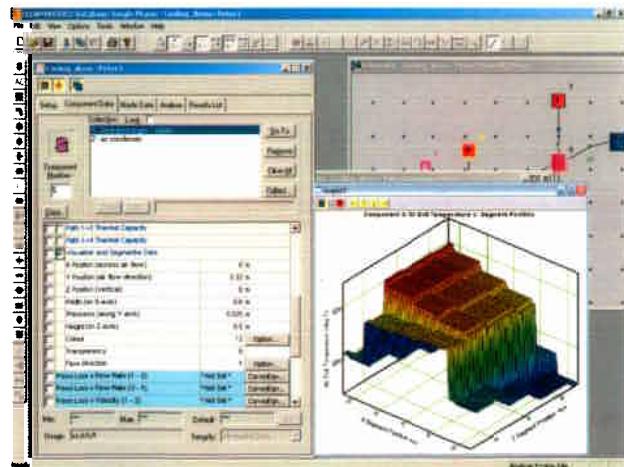
Thermal model simulates steady state conditions during cooling testing

Thermal Tool - Technology

Unclassified

- Highly interactive tool with advanced features focusing on efficiency, accuracy, reliability and usability
- Facilitate connection between simulation and test process

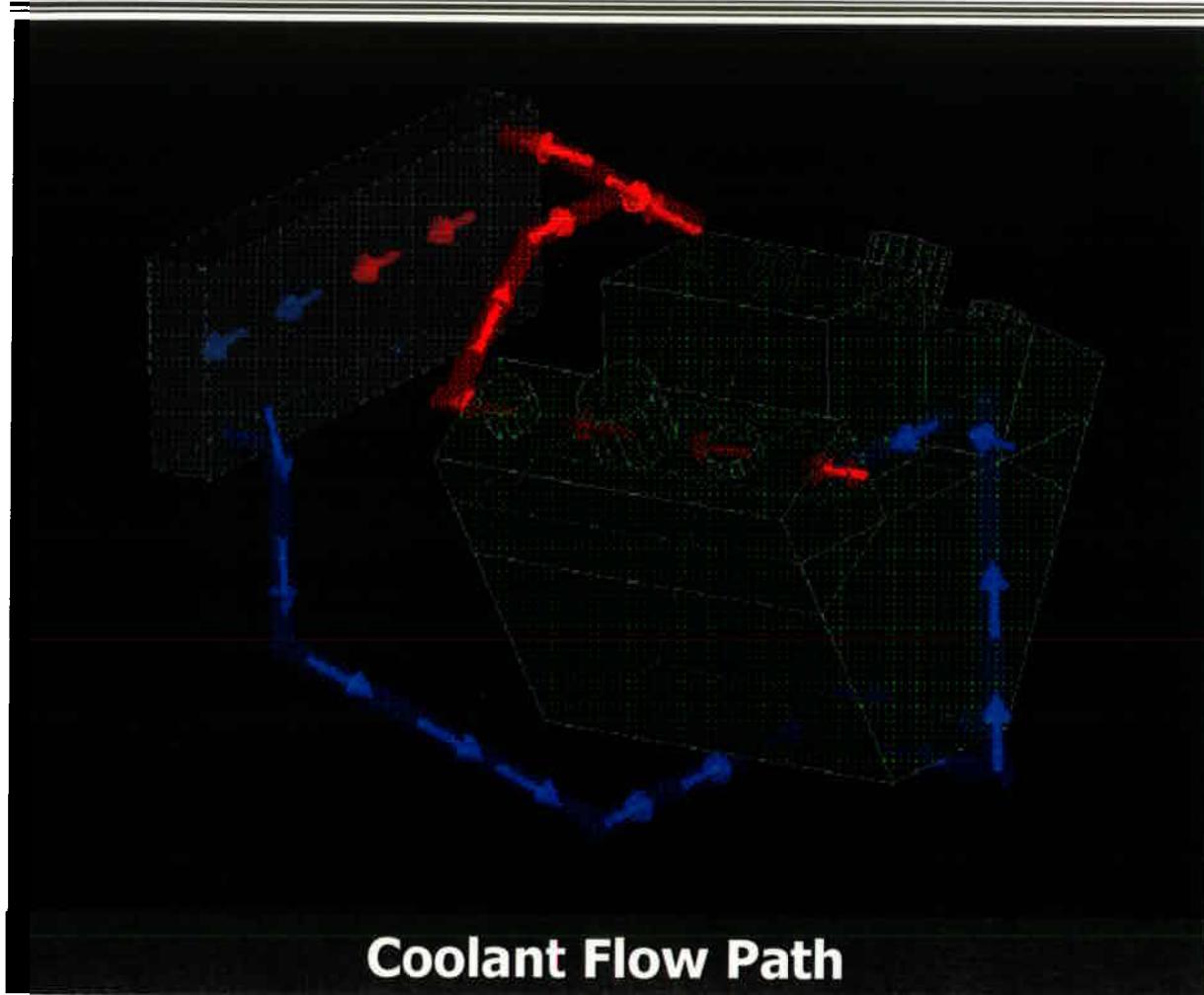
Thermal Tool



Thermal Test

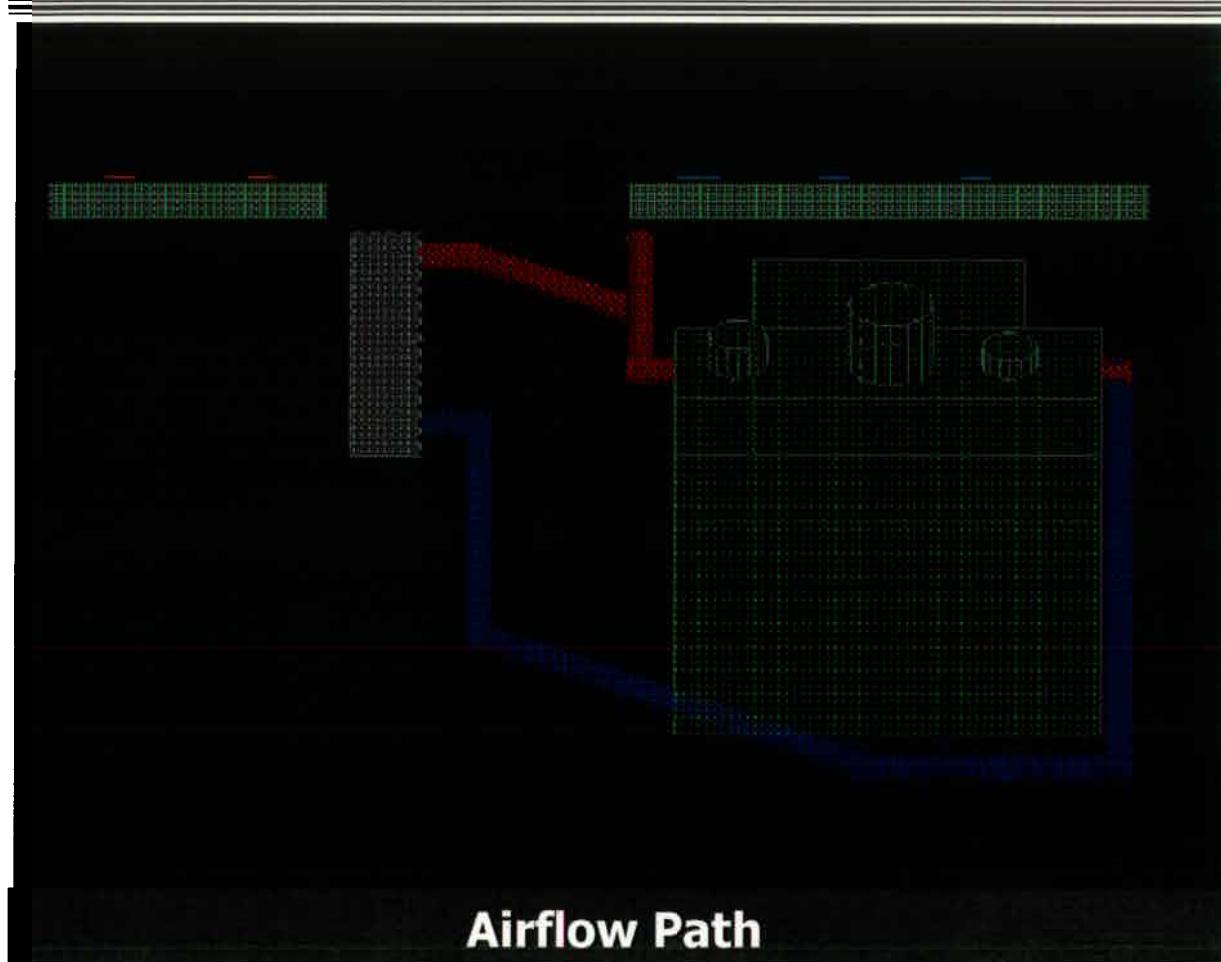


Thermal Tool - Function



- Model the coolant and airflow heat balance
- Predict critical temperatures
- Produce same results as test

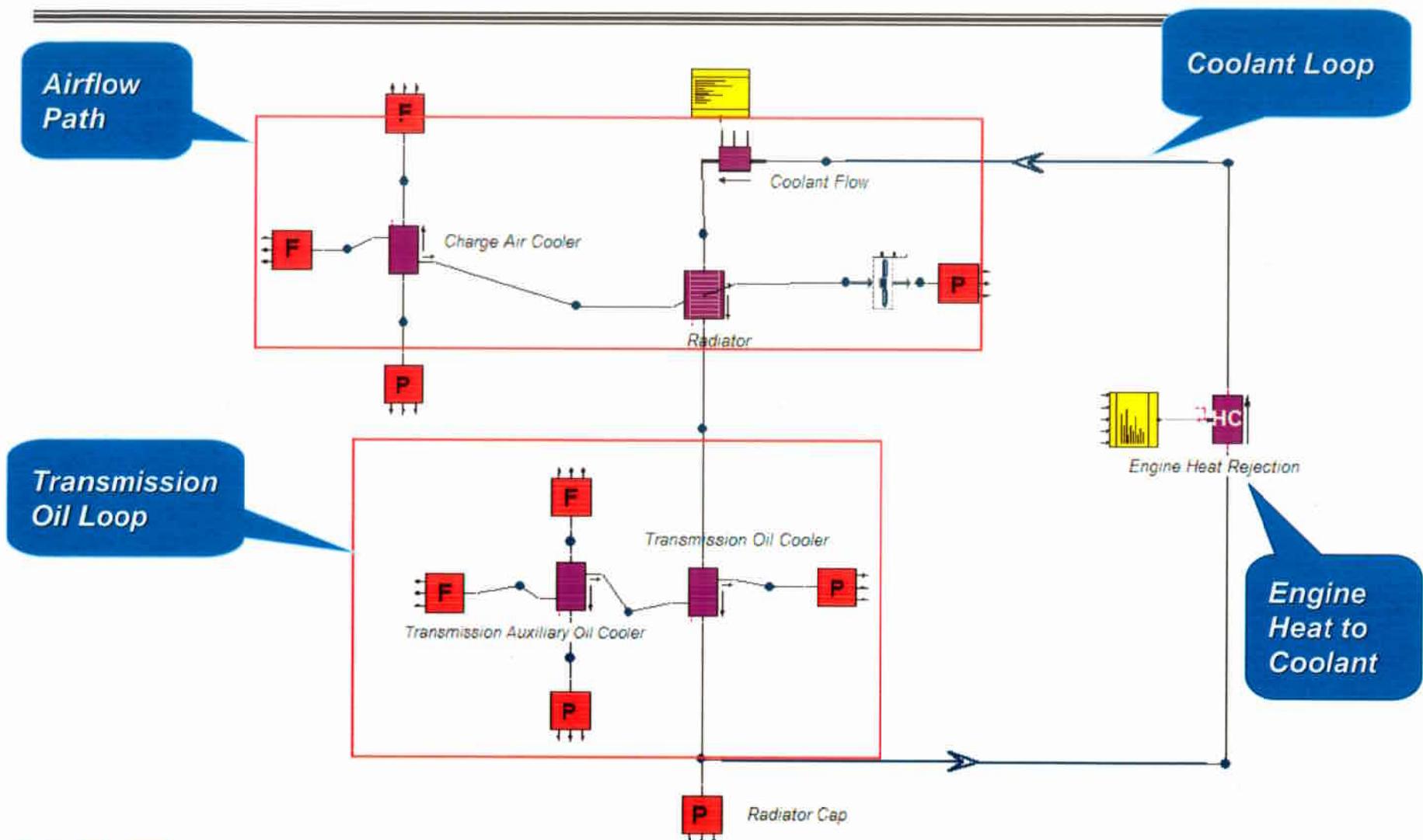
Thermal Tool - Function



- Model the coolant and airflow heat balance
- Predict critical temperatures
- Produce same results as test

Thermal Tool – Function

Unclassified



Pilot Project – Medium Tactical Vehicles

Unclassified



M1087 Expandable Van



M1093 Cargo Truck



M1098 Wrecker



M1090 Dump Truck



Common Chassis

Commonality

Chassis

Drive Train

Differences

Payloads

Mission Requirements



Material Handling
Equipment



Load Handling
System



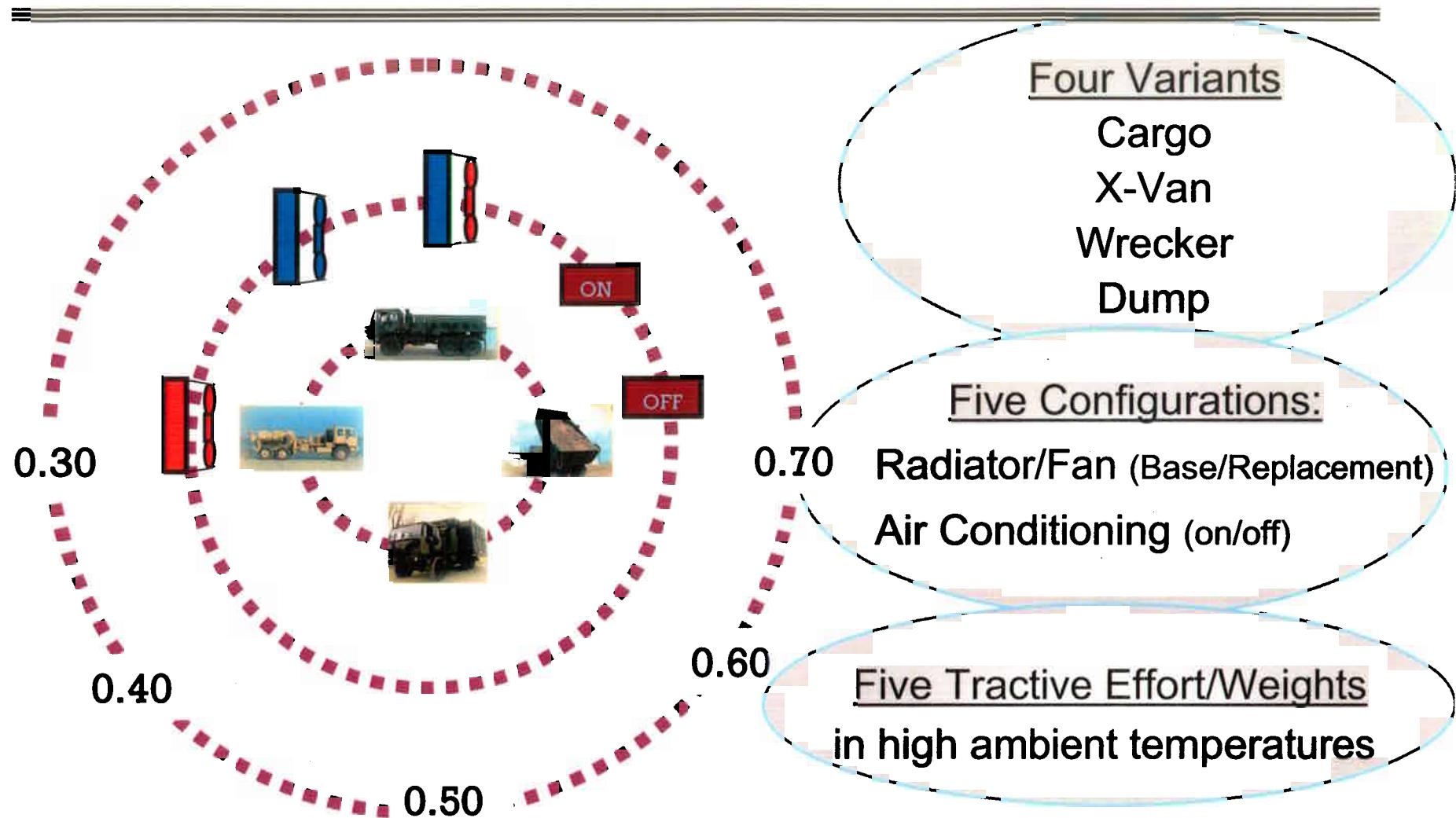
MTV



M1088A1 Tractor

Pilot Project – Test Matrix

Unclassified



Tradition approach only captured 40% of the desired data within this test matrix.

Unclassified

06CV-190

Pilot Project – Work Completed

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Major objectives have been accomplished

- Captured test data from four MTV variants



M1093 Cargo Truck



M1087 Expandable Van



M1098 Wrecker

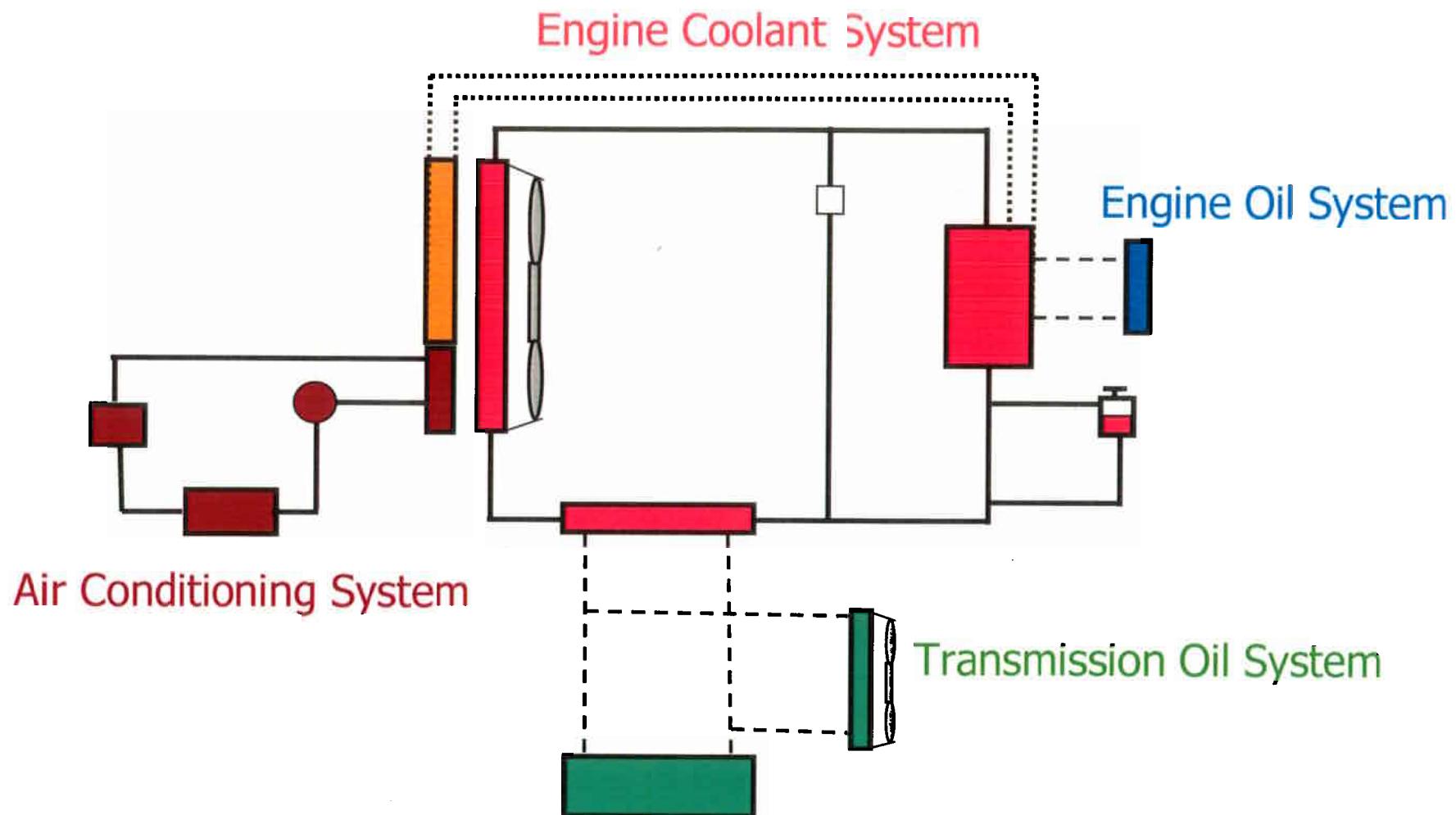


M1090 Dump Truck

- Developed several thermal models
- Validated models using actual test data

Thermal Tool - Thermal Systems

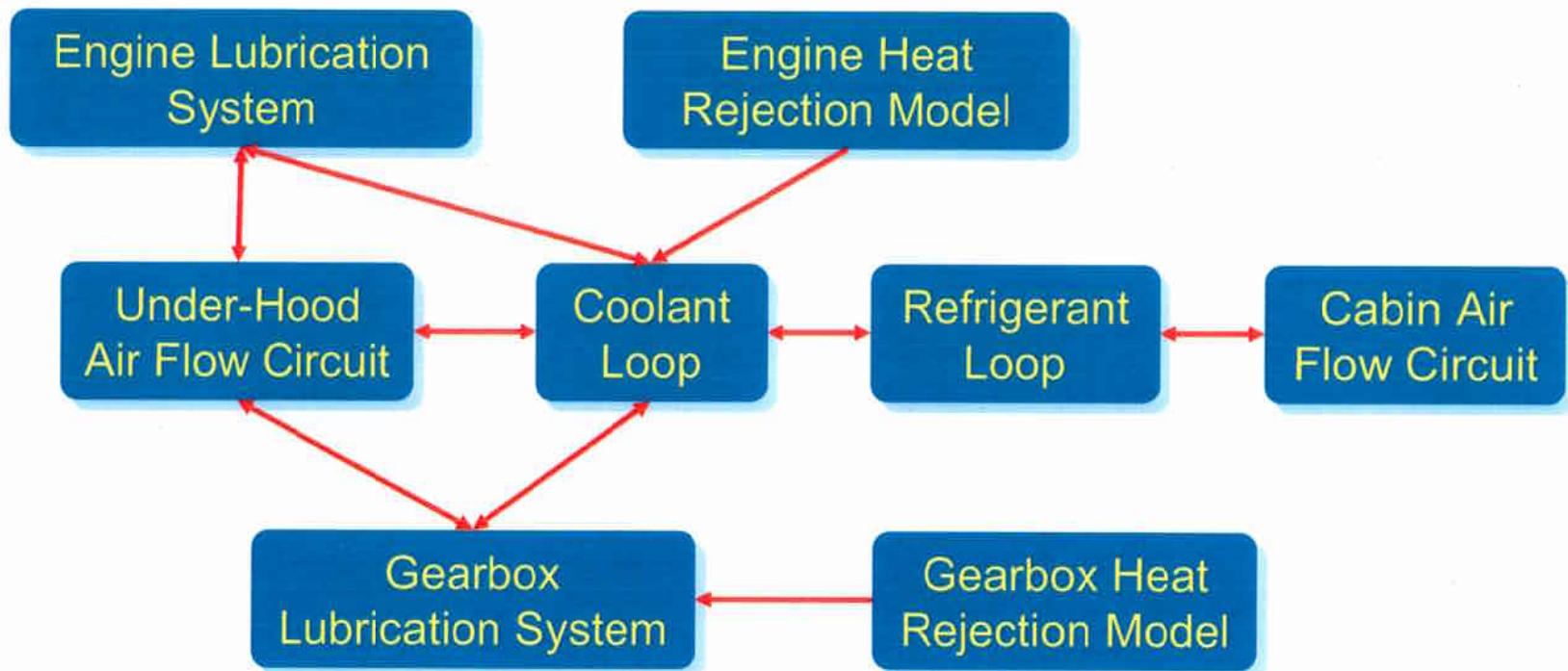
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Thermal Tool - Responsibilities

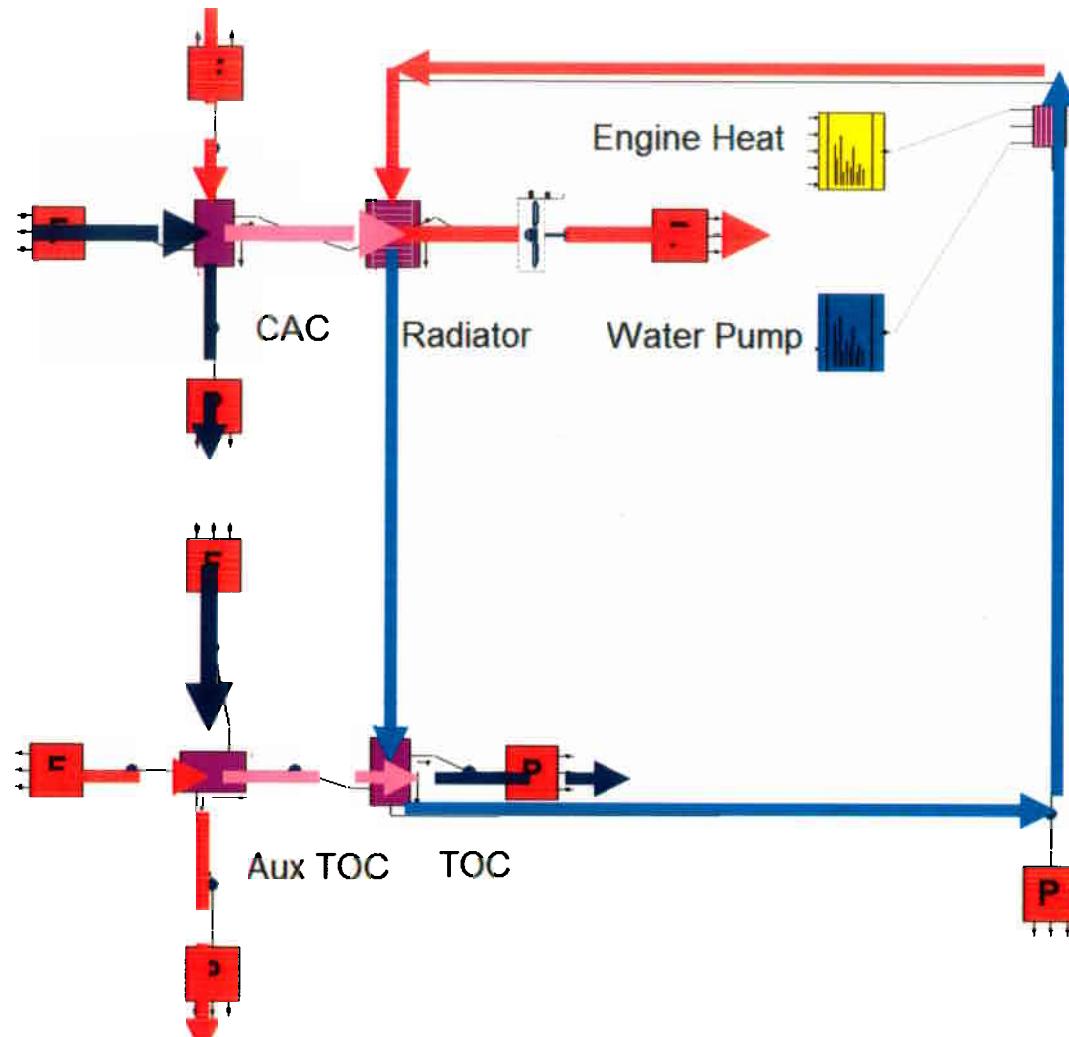
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Thermal system interaction:



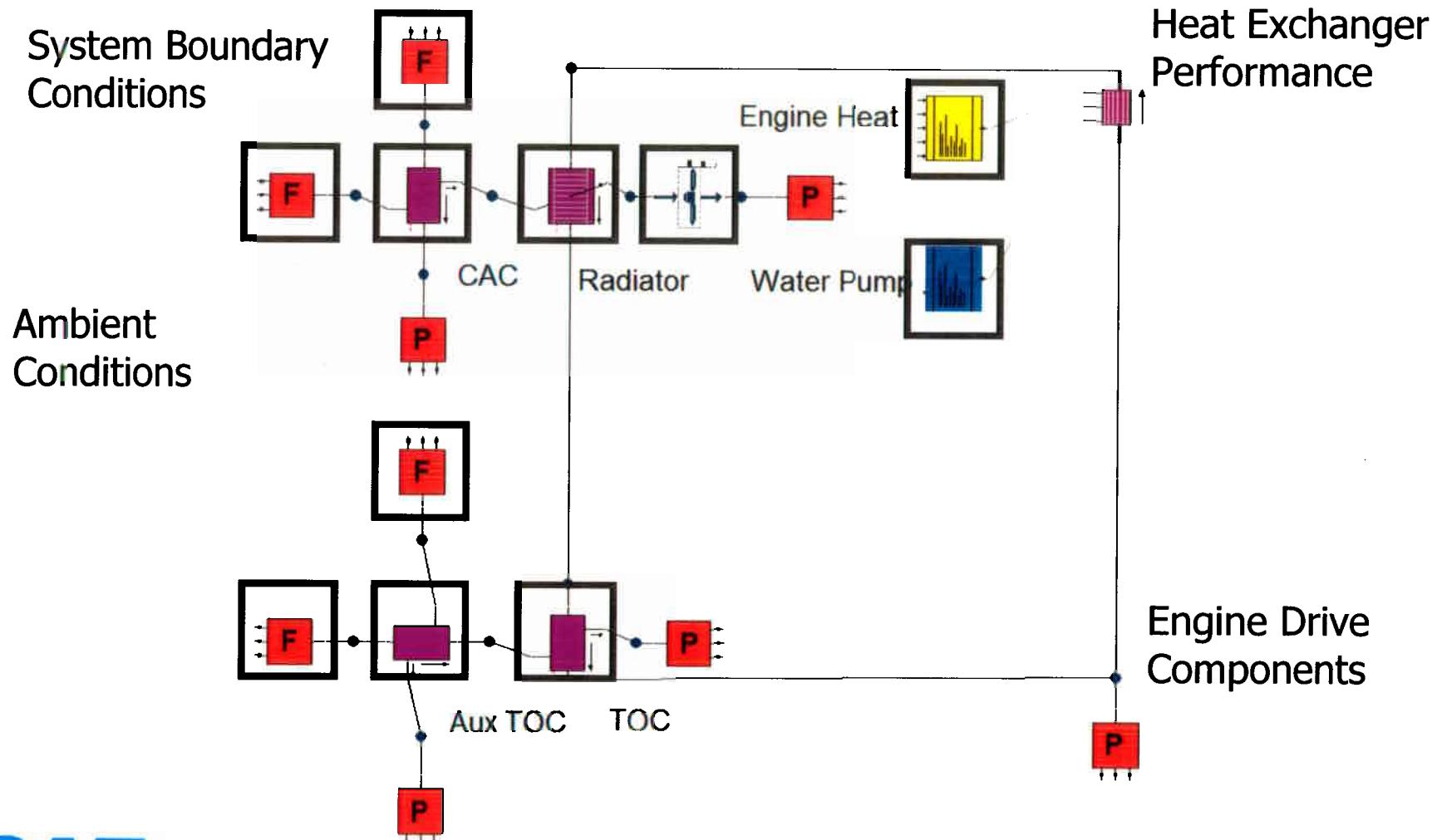
Thermal Tool - 1D Model Set Up

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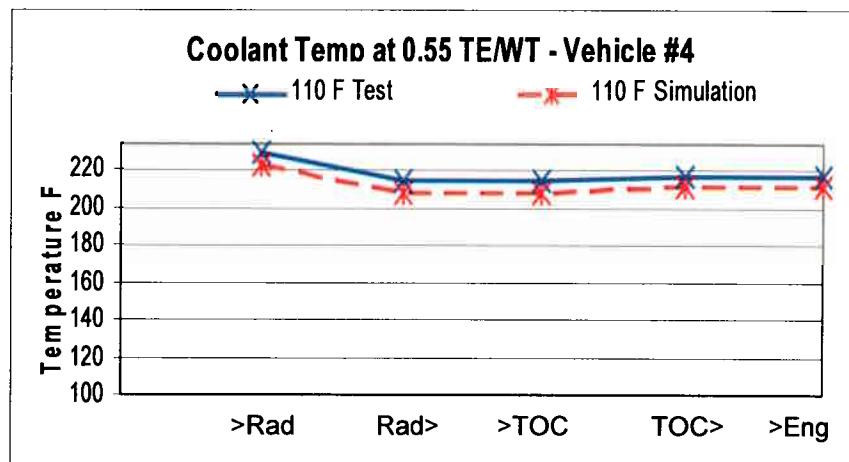
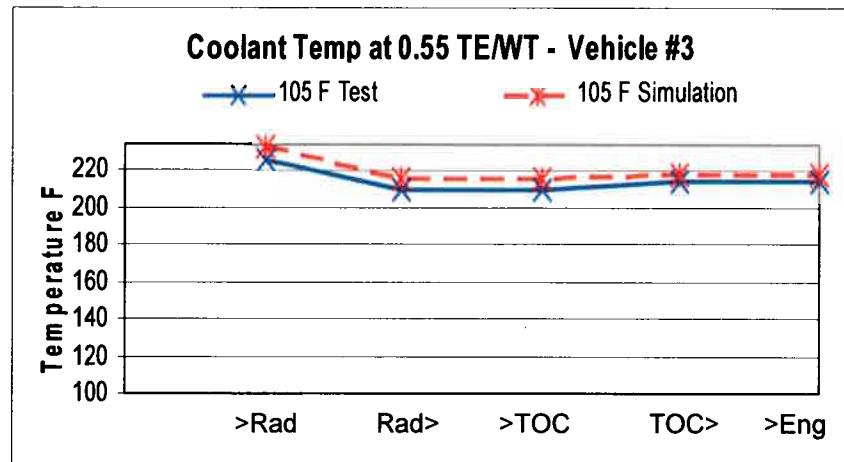
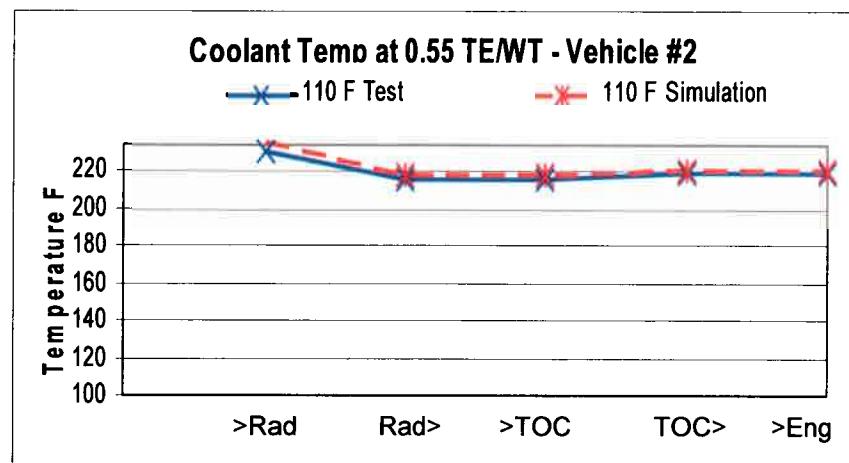
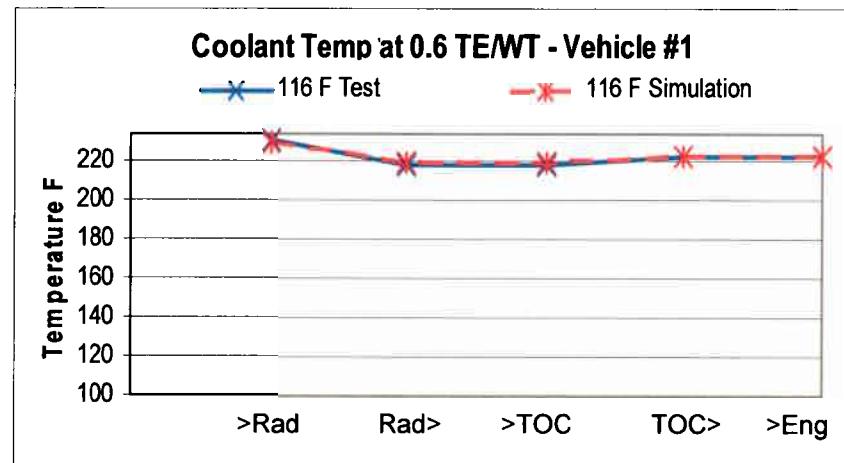
Thermal Tool - 1D Model Set Up

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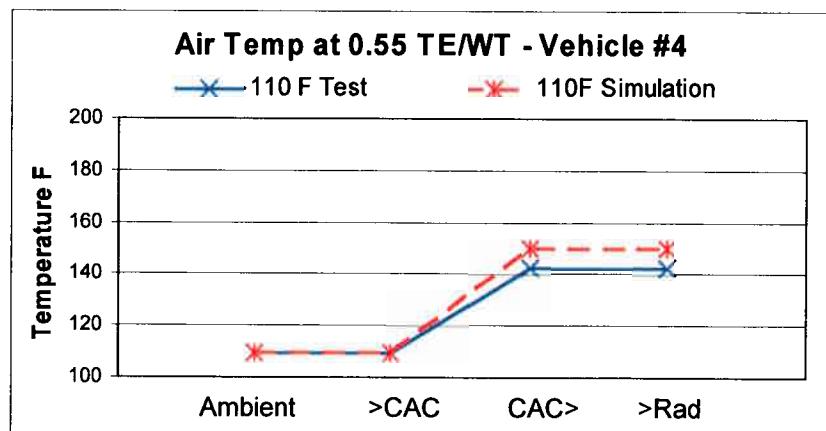
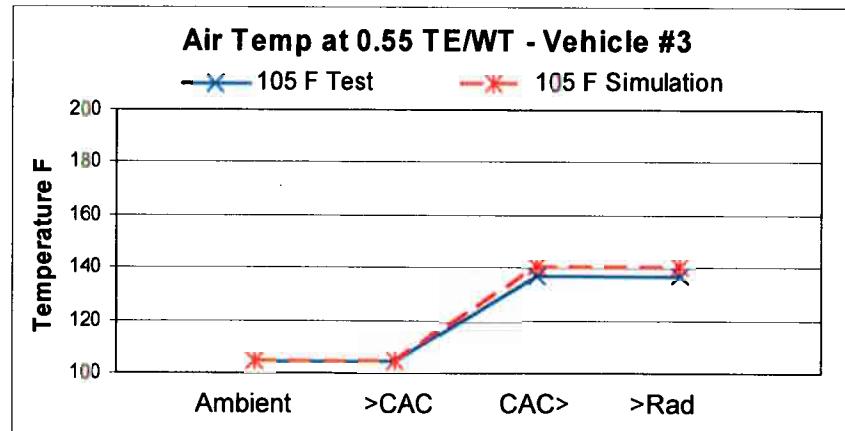
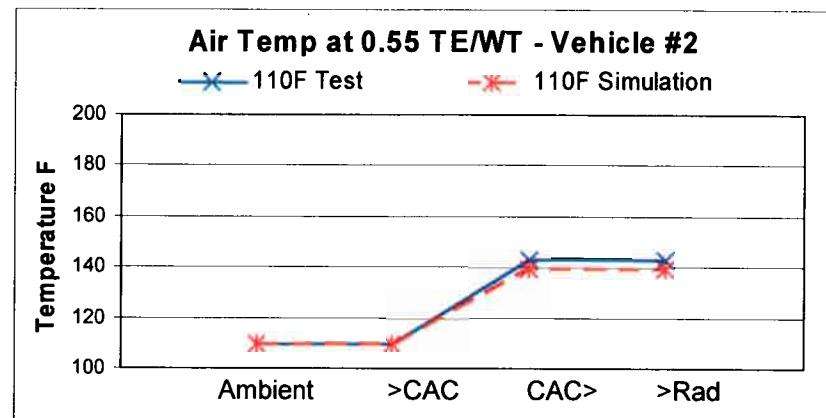
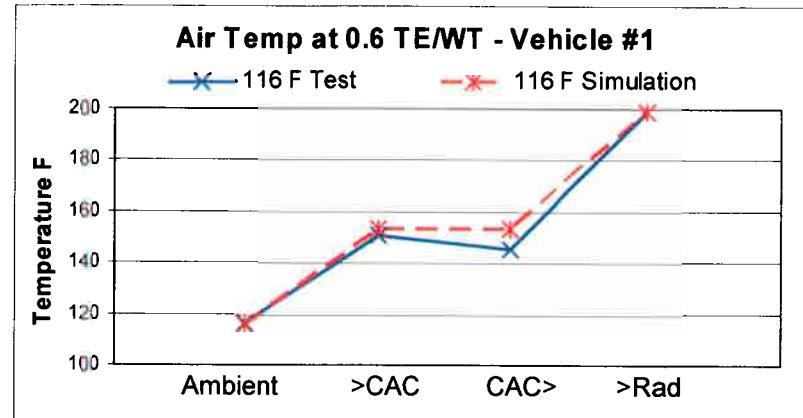
Results – Coolant Temperature

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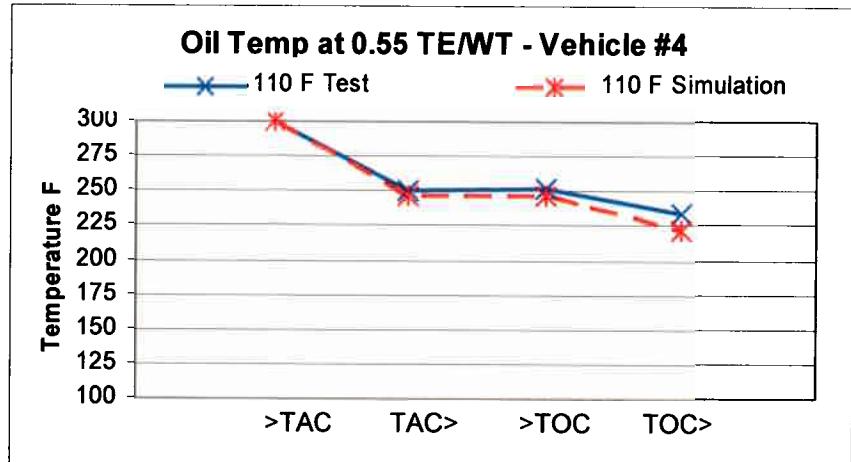
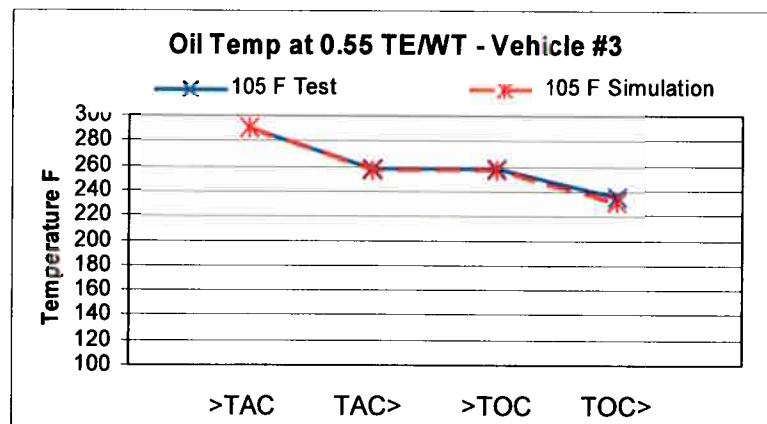
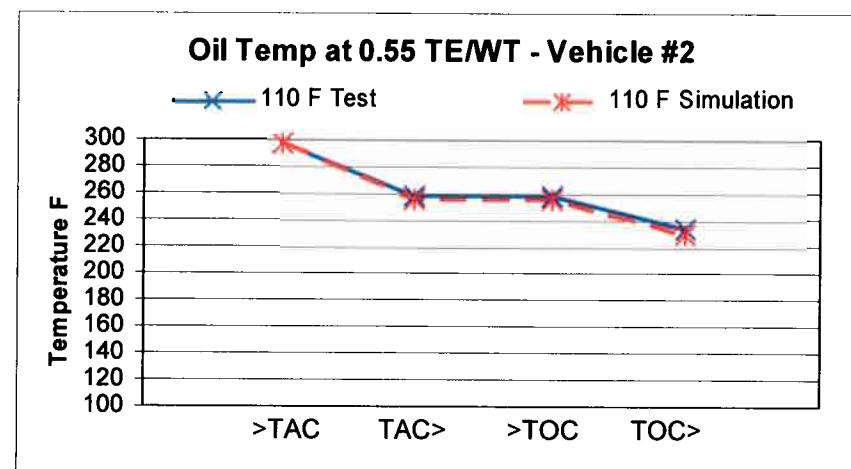
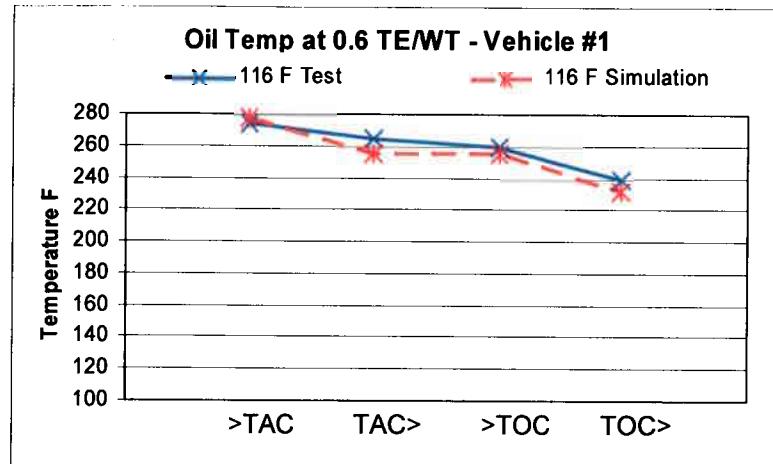
Results – Air Temperature

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Results – Transmission Oil Temperature

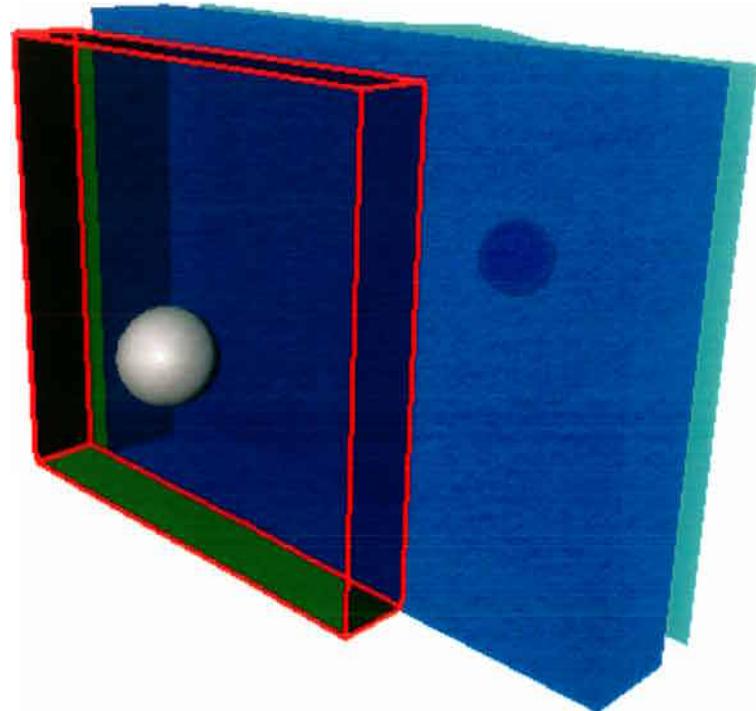
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Next Steps – Additional Variables

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- Performance
 - Equal or better than existing exchanger under same operating conditions
- Variable Geometry
 - Height, width, and depth
- Variable Location

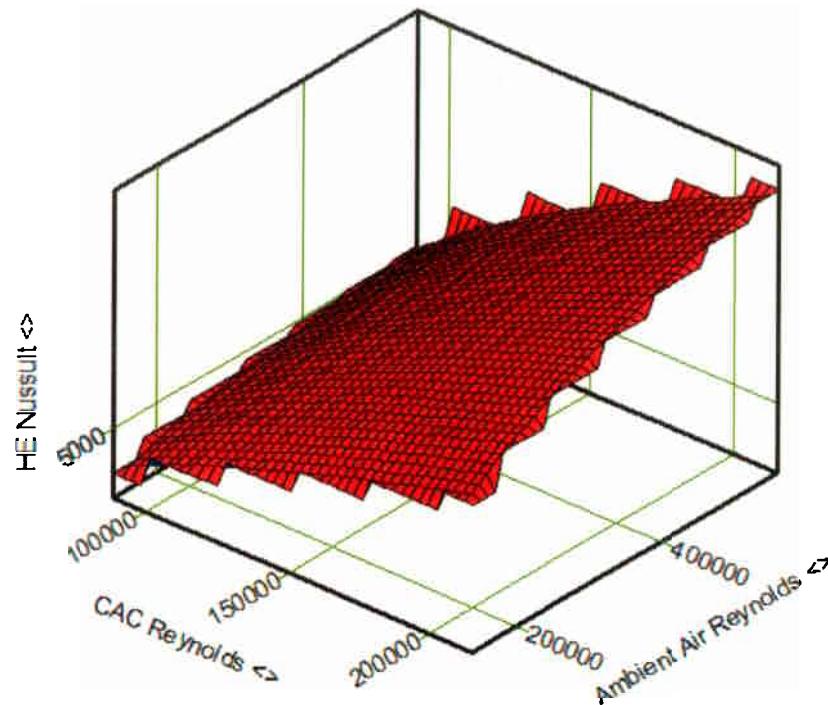


Next Steps - Performance Input

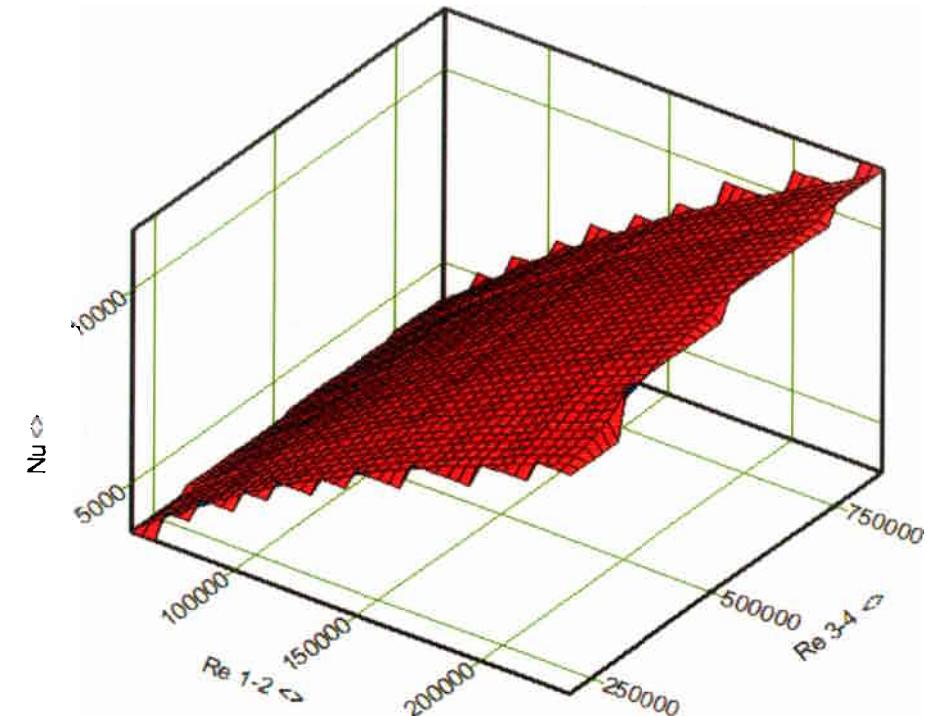
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Charge Air Cooler Nusselt Number vs. Re12 vs Re34 V3



CAC Nu v Re1-2 v Re3-4



Next Steps – Automated Approach

Unclassified

Nusselt Number Calculator V5.user.xls

Flowmaster Nusselt Number Calculator

Project and Component Location

Database Folder: C:\Flowmaster_Database\10\Database\Flow_v5
 Project Folder: C:\Flowmaster_Database\10\Database\Flow_v5
 Project Name: AVS_10285
 Network Name: AVS_Example
 Surface Title: Fun_FM_Macro_Test

Flow Exchanger Properties

Thickness [m]: 0.016
 Hot Side: Glycerin Water 80/20
 Fluid Type: Glycol Water 80/20
 Flow Area (m²): 1.0E-03
 Hydraulic Diameter [m]: 0.000825
 Inlet Pressure [bar]: 1
 Air Side: Air Air 100% gas
 Fluid Type: Air Air 100% gas
 Flow Area (m²): 0.3312
 Hydraulic Diameter [m]: 0.001
 Inlet Pressure [bar]: 1013

Required Calculation Steps

1. Click to populate dropdown menus with fluids from FLOWMASTER® database
2. Click to calculate Nusselt number
3. Click to add to Flowmaster
4. Update framework
5. Start Flowmaster
6. Enter 'Database Dir' and 'Project Dir'
7. Enter 'Measured Data'
8. Click button 1 to read database 'Auto'
9. Select required fluids from dropdown menus
10. Click button 2 to calculate Nusselt Number
11. Enter in 'Surface Title'
12. Click button 3 to add your surface to FM
13. Click button 4 to run FM analysis and view results

Results

Temperature [C]	Heat Flux [W/m ²]

Note: Highlighted cells in this column indicate values that have been limited to prevent errors.

Required Data **Optional Data (give T or Duct)** **Data Retrieved from FLOWMASTER®** **Calculated Results**

Mass Flow Rate [kg/s]	T _{in} [C]	Hot Side				Air Side				ΔT _i [m]	[m]	[m]	q / (W/m ²)	U	Heat Flux [W/m ²]	Nu			
		Hot Side	Air Side	Hot Side	Air Side	Hot Side	Air Side	Specific Heat [W/kg K]	ν [N]								Specific Heat [W/kg K]	Thermal Cond. [N/m K]	Viscosity [N s/m ²]
0.328163333	8.071804	80.8	25.4	59.571871	59.840333	24215.545	3554.880394	0.0012206	1010.339763	0.027384644	138E-05	514	1163	815.222	0.1429394	2553.1934	454.8111	126.25494	2076.0198
161916667	0.905342	80.8	27.3	79.123878	67.708300	32953.064	3505.039626	0.0013067	1010.283963	0.027503045	1543E-05	535	5005.62	814.533	0.1060947	2950.6894	2536.7663	125.3032	2251.5828
0.456	0.805006	80.9	25	67.920581	65.94029	30392.572	3672.366102	0.0011874	1010.226466	0.027579523	1543E-05	519	2344.47	824.955	0.2408951	4227.1654	100.0925	126.92469	2452.3617
0.578666667	0.89323349	81.5	25.8	72.557378	68.811889	31350.352	2682.872026	0.0010552	1011.24938	0.027688395	1543E-05	517	3505.66	817.68	0.1729747	4186.0685	1565.9475	125.34723	2401.7409
0.328166667	1.397913	80.7	30.4	63.057391	62.250887	32114.024	3516.120209	0.0013080	1003.820956	0.02701968	157E-05	503	161.75	1404.93	0.5455576	4563.7301	413.85951	219.08774	2685.895
0.3275	1.98393964	80.9	20.3	49.00552	48.075086	36975.50	3502.702244	0.0010406	1003.819321	0.020029	1504E-05	50.0	156.36	20014	0.612047	4791.077	392.51639	314.28115	2640.9802
13554666667	0.77084899	80.4	27.2	76.675024	70.202395	32415.2	3589.03024	0.0010301	1010.307077	0.027860359	1543E-05	531	702.65	778.354	0.0597262	4407.731	3184.5969	119.47113	2548.0728
1.239	0.80454169	91.4	30.6	74.424703	70.3918	32348.76	3685.28426	0.0010307	1010.441523	0.02773825	155E-05	50.8	437.57	812.962	0.137305	4537.883	2922.331	124.88908	2612.427
0.656132323	1.3817892	81.3	25.3	63.88888	57.495333	40705.652	3554.90576	0.001545	1009.97201	0.027250048	1522E-05	53	2338.77	1391.57	0.3284931	4641.091	959.78362	217.0534	2724.5265
0.9755	1.3679420	81.9	29.3	68.282968	59.959972	44039.772	3576.578066	0.0010857	1010.016307	0.027341776	1527E-05	50.0							
0.328166667	3.16237245	82.7	21	47.533203	44.45586	40736.009	3623.904662	0.0014922	1003.779793	0.02869557	15E-05	51	156.42	389.31	0.6955553	5324.2238	2914.082	502.70225	385.6999
0.6555	1.98364702	81.7	29.5	61.205202	52.362371	47902.363	3593.95327	0.0011094	1003.872311	0.02700464	1543E-05	532	2333.55	2003.25	0.3805032	5054.1246	930.42723	313.452	2986.3377
0.328233333	4	80	30	42.008423	40.86241	43070	3515.34417	0.0016231	1003.747461	0.025707394	157E-05	50	155.71	4038.7	0.7588447	639.5434	340.77213	639.67007	3626.4477
123333333	1.39406349	81.4	25.9	71.06732	63.895933	47857.426	3579.47617	0.0010705	1010.17102	0.027545504	1543E-05	515	452.03	1405.25	0.2007484	5671.942	2039.7257	236.91237	2294.5875
129433333	1.09660108	80.8	27.8	68.39028	56.925413	57721.086	3572.950034	0.0010307	1003.344103	0.027203629	1519E-05	52.9	462.46	206.46	0.235945	5941.2269	1973.8456	314.44449	3437.7208
0.975833333	1.15521416	82.4	31.9	67.05795	50.994056	53492.877	3573.039558	0.0010175	1010.072443	0.027444409	1534E-05	50.5	3488.63	1974.31	0.3038023	6090.8063	1417.5121	305.24218	3645.8908
1628	1.99442342	80.5	27.5	79.208130	57.17346	58680.373	3578.693052	0.001054	1003.946031	0.027228924	152E-05	53	5788.63	201.24	0.194194	505.6704	2532.19	312.25901	2477.3907
0.657033333	3.2126439	81.9	31.4	57.017706	48.880833	66745.00	3582.450461	0.0012453	1003.86196	0.027059713	1509E-05	50.5	2336.82	3244.32	0.4808389	6259.6702	3103.0483	503.02165	37012485

Next Steps - Results

Unclassified

Top Tank Temperatures

	Vehicle A	Vehicle B	Vehicle C
Heat Exchangers			
X	180 °F	200 °F	210 °F
Y	180 °F	200 °F	210 °F
Z	180 °F	200 °F	210 °F

Next Steps - Observations

Unclassified

- Simulation accurately represents cooling system performance
- Thermal simulation simplified complex interactions
- Initial validation process utilized:
 - Pre-processed component test data
 - Comprehensive vehicle test data
- Process enables rapid and accurate analysis
 - Heat exchanger options
 - Multiple vehicle variants
- Validating process for future heat exchanger evaluation

Thanks for attending!

Questions?

Mary Goryca, US Army Tank Automotive Research,
Development and Engineering Center

Neil Slyva, Flowmaster USA

